8 Packaging and the Shelf Life of Yogurt

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8.1 ORIGINS AND DEVELOPMENT

Yogurt is a modern food with ancient origins. It originated perhaps 10,000–15,000 years ago, probably in the Middle East, from adventitious contamination by lactic acid bacteria of milk in traditional containers such as earthenware pots or containers made from animal skins. Over time, the preservation of milk by making fermented milk products spread around the world, wherever milking animals were domesticated, and numerous types of traditional fermented milk products emerged, depending on the source of milk and the microbial cultures and manufacturing methods used. Tamime and Robinson (1999a), Chandan (2006), and Vasiljevic and Shah (2008) have provided detailed accounts of the origins and development of yogurt and fermented milk products.

During the twentieth century, yogurt became popular in Western countries, first in a fairly traditional form, as a "set" product, fermented in the containers used for its sale; then, to add variety, with a fruit preparation (similar to a jam) added to the bottom of the containers, with the yogurt above the fruit—the so-called fruit-on-the-bottom yogurts; then, as "stirred" or "Swiss-style" yogurts, with the yogurt coagulum made in fermentation tanks, cooled, and filled into the final containers, often with fruit preparation mixed through the yogurt. The latter half of the twentieth century saw a great increase in the variety of products in terms of fat content, texture, acidity level, and culture. During this period, packaging technology also developed significantly, and the forms of packaging for yogurt products became diverse as well. Product differentiation and marketing drove consumer interest and sales, so that by the end of the twentieth century global food companies were making and marketing spoonable and drinkable yogurt products around the world under globally recognized brand names.

Although yogurt is still made by traditional means in some parts of the world, industrially yogurt products in all their various forms are made and packaged using sophisticated methods, making use of state-of-the-art technology for culture preparation, processing, packaging, and distribution. From a product that in ancient times allowed milk to be preserved for a few days, there now exist products containing live starter and probiotic cultures that have refrigerated shelf lives of 6 weeks or more. There are also pasteurized yogurt products in some markets in which the cultures have been killed by heat treatment after the product has been made, and these may have refrigerated or ambient shelf lives measured in months, depending on the manufacturing method and packaging material.

This chapter addresses modern spoonable and drinking-yogurt products and technology and the influence packaging materials and systems have on their shelf life.

8.2 YOGURT MANUFACTURING PROCESSES

The common types of yogurt are set, stirred, and drinking yogurt, and they are found in most developed markets around the world. The main production steps are shown in Figure 8.1.

For all types of yogurt, the first step is the preparation of a yogurt mix and the heat treatment of this mix. The milk mix is formulated to have the required amount of milk fat, milk protein and other nonfat milk solids, and added sugars, stabilizers, flavors, and colors, if these are used. The solids level, particularly the protein level, affects the texture and firmness of the yogurt coagulum, and so it is common to increase the nonfat solids of the mix for set and stirred yogurts. This can be done by adding skim milk powder or skim milk concentrate during the preparation of the milk mix or by using membrane separation techniques such as reverse osmosis or ultrafiltration to concentrate skim milk or the protein in skim milk. Where regulations permit their addition, stabilizers such as

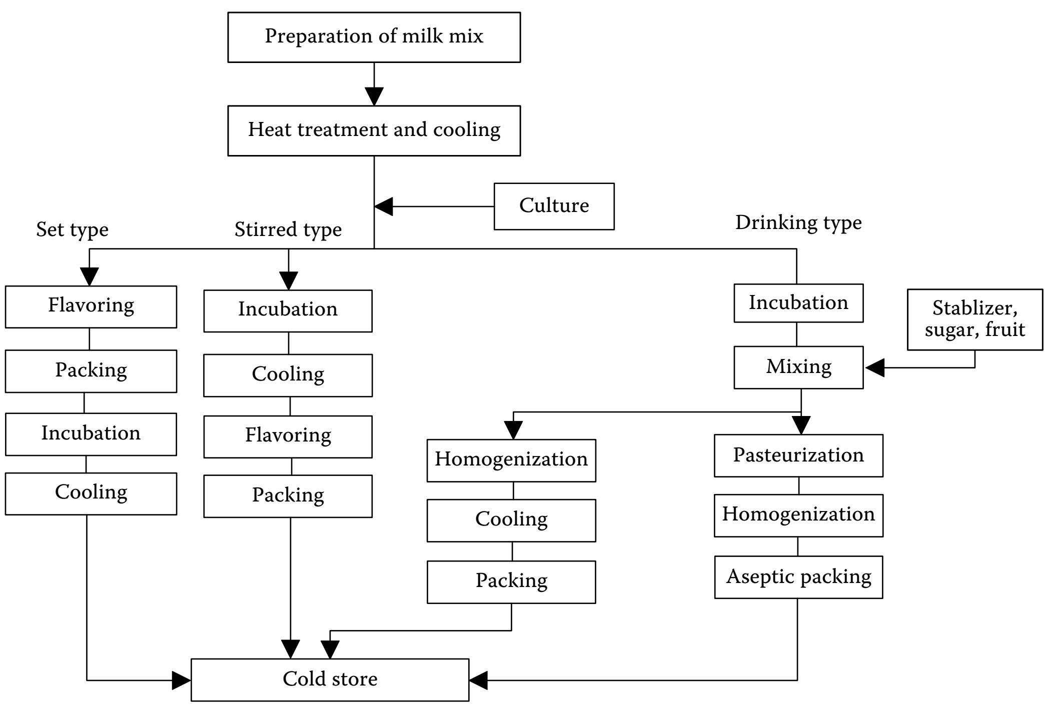

FIGURE 8.1 Production steps for set, stirred, and drinking yogurts. (Redrawn from Bylund G. 1995. Cultured milk products. In: *Dairy Processing Handbook*. Lund, Sweden: Tetra Pak Processing Systems AB, p. 248.)

gelatin, modified starches, pectin, and gums can also be used to make the coagulum firmer and to improve its water-binding properties, reducing the tendency for serum separation from the coagulum (so-called syneresis).

The yogurt mix is heat-treated for two reasons: first, to kill pathogens and spoilage microorganisms and, second, to denature the milk proteins and bring about interactions between them that increase their water-binding capacity and hence the firmness of the yogurt coagulum (Chandan and O'Rell, 2006; Tamime and Robinson, 1999b). It is common to heat-treat the milk mix for yogurt making at around 90–95°C with a holding time of about 5 min (Bylund, 1995). This heat treatment is normally applied in a continuous flow system that includes a homogenization step to ensure the milk fat remains in a homogeneous emulsion throughout the milk mix during fermentation.

Stirred yogurt is the most widely made and sold type of yogurt. Following heat treatment, the milk mix is cooled to the fermentation temperature of around 42–43°C (or lower if probiotic organisms, such as *Bifidobacterium* subsp., with lower optimum growth temperatures are added) and pumped into a stainless steel fermentation tank. Yogurt starter culture, consisting usually of a mixed culture of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*, is inoculated into the yogurt mix and fermentation takes place. In a few hours (the time depending on the rate of addition of starter culture, its activity, and the temperature), a coagulum will form due to acid produced by the starter organisms. When the pH of the coagulum has reached 4.2–4.6, depending on the exact production system used, it is "broken" by pumping it from the fermentation tank (sometimes with slow stirring) and then cooled in a heat exchanger and pumped to a storage tank, where it is ready for mixing with a fruit or flavor preparation and packing. In many production systems the temperature to which the coagulum is cooled is between 15°C and 22°C (i.e., a precooling), with final cooling to the distribution temperature of less than 5°C achieved in the final package. However, the exact cooling temperatures used for precooling vary among production systems.

Pasteurized or long shelf life yogurt may either be heated in the container after filling, at temperatures above 50°C for times of around 15–30 min, or heated before filling and hot-filled at temperatures of up to 70°C. The shelf life will vary according to the exact conditions used. For pasteurized yogurt, an appropriate stabilizer system must be used to ensure a satisfactory texture following the heating and cooling steps.

The process for drinking yogurt shares the steps of yogurt mix preparation and heat treatment, and of inoculation and fermentation, with stirred yogurt. Following these steps the coagulum is mixed with a flavoring mix, often incorporating some fruit juice, and the resultant mixture is homogenized. There is usually a stabilizer present in the formulation that enables a smooth beverage product to be produced, free of any graininess in texture.

Frozen yogurt products (either hard-frozen or soft-serve) are also produced and sold in significant quantities in some markets. The process for making these products relies essentially on ice-cream manufacturing technology, except that yogurt is used as a main component in making the ice-cream mix before churning and freezing. The packaging materials, containers, and filling equipment are the same as for hard-frozen or soft-serve ice-cream.

Yogurt can also be dried into a powder for use in manufacturing other formulated foods. Packaging materials, containers, and filling equipment are the same as for powdered products such as whole milk powder.

8.3 YOGURT CONSUMPTION

In some countries, including the Netherlands, Finland, Sweden, Denmark, France, and Germany, the consumption of fermented milk products has historically been very high. Chandan (2006) reported that in all these countries consumption of fermented milk in 1998 was in excess of 25 kg/person/year. Moreover, in the period 1998–2004, the per-capita consumption of yogurt in Western Europe increased from approximately 13 to about 15 kg/person/year (USDA, 2006). In recent years there has been a strong growth in yogurt consumption in many other countries, including the United

States, up from 0.9 kg/person/year in 1975 to 3.7 kg/person/year in 2002 (USDA, 2004); Canada, up from 3.04 L/person/year in 1987 to 7.13 L/person/year in 2007 (Canadian Dairy Information Centre, 2008); and Australia, up from 5.6 kg/person/year in 2001/2002 to 6.9 kg/person/year in 2007/2008 (Dairy Australia, 2009).

Yogurt is well recognized as a healthy product, and it may be expected that consumption will continue to grow in many markets in line with trends toward healthy eating, including in Asian markets, where the per-capita consumption of milk and dairy products is currently low. In established dairy countries, the market for yogurt products is also characterized by innovations in formulations (e.g., the addition of probiotic cultures) and packaging (e.g., multipacks; pack size and shape differentiation using, for example, open-mold, form–fill–seal technology; tubes for products for children; reclosable pouches; and label styles, including shrink-wraps and paperboard tear-off labels), which helps to bring new consumers into the market and to drive consumption.

8.4 QUALITY ATTRIBUTES OF YOGURT

During the production of yogurt, the starter cultures grow and produce lactic acid. This reduces the pH to below the isoelectric point of the milk proteins and causes coagulation, producing the characteristic gel structure and contributing to the clean, acid taste of the product. The starter organisms also produce a range of other flavor compounds comprising volatile and nonvolatile organic acids, and carbonyl compounds such as acetaldehyde, acetone, acetoin, and diacetyl. Many starter cultures also produce polysaccharide materials, which increase the thickness and stability of the yogurt gel (Shah, 2003).

Tamime and Robinson (1999c), Karagül-Yüceer and Drake (2006), and Lewis and Dale (2000) have given good descriptions of the desirable sensory properties of yogurt. Set yogurt should have a smooth, junket-like appearance and a firm, cuttable texture. Stirred yogurt should have a smooth, glossy, thick texture. There should not be excessive whey at the surface of either product. Both set and stirred yogurt should have a fresh, clean, slightly acidic taste, with the characteristic note of acetaldehyde, sometimes described as "green." There should not be excessive postacidification in the product caused by continuing acid development by the cultures in the package following final cooling to refrigeration temperatures.

Drinking yogurt products vary widely in viscosity and mouthfeel, from products that are quite thick to those that have a thinner, more refreshing mouthfeel. Generally, the solids levels of drinking yogurts are lower than those of spoonable products.

The composition of yogurt products varies according to the tastes of the market and the specific segment in the market. The milk fat content may vary from virtually zero for skim milk yogurt products to more than 4% for "indulgence" products and even up to 8% or 9% for Greek-style products. Protein levels may be the same as those of the milk from which the yogurt is made (between 3% and 3.5%) or significantly greater in order to increase the firmness of the coagulum. Yogurt contains the nutrients of the milk fat, milk protein, lactose, and the minerals and vitamins of its milk components, as well as other nutrients, such as those from added fruit preparations, and is widely recognized as a nutritious product.

Probiotic microorganisms have been defined by Fuller (1989) as live microbial food supplements that benefit the health of consumers by maintaining or improving their intestinal microbial balance and, when added to yogurt, can add to its health-promoting properties. Metchnikoff (1908), in his famous book *The Prolongation of Life*, proposed a theory that the regular consumption of milk soured with lactic acid bacteria could prolong life by combating toxic bacteria in the gut. Metchnikoff's work provided the original inspiration for the search for and discovery of probiotic microorganisms. Many such organisms have been discovered and found to have positive health effects, and in recent years it has become increasingly common to add probiotic cultures to both spoonable and drinking-yogurt products (Shah, 2006). Talwalkar and Kailasapathy (2004)

and Vasiljevic and Shah (2008) have reviewed the use of probiotics in commercial yogurt products and concluded that *Lactobacillus* spp. and *Bifidobacterium* spp. are the most common probiotic bacteria added to yogurt. Probiotics are an example of "functional" ingredients or supplements added to foods, and for them to be effective, it is generally agreed (Shah, 2000; Talwalkar and Kailasapathy, 2004) that there needs to be a concentration of at least 10^6 live organisms per gram in the yogurt at the time of consumption; higher levels are advocated by some (Vasiljevic and Shah, 2008). As some probiotic organisms are sensitive to O_2 and their survival in yogurt may be related to O_2 levels present (Dave and Shah, 1997; Talwalkar and Kailasapathy, 2004), the packaging material may be important in maintaining the level of probiotic organisms in the product (Miller, 2003; Miller et al. 2002; Talwalkar, 2003; Talwalkar and Kailasapathy, 2004), although this is still open to some conjecture.

Yogurt is also a very suitable product for the addition of other functional ingredients and supplements, such as vitamins and omega-3 long-chain fatty acids. These may be sensitive to O_2 levels in the product, as some (e.g., omega-3 fatty acids) are susceptible to oxidation.

The shelf life of yogurt products is determined by the time the product remains safe to eat, the time its functional claims remain true to label or to regulatory requirements, and the time its sensory properties remain acceptable to consumers. Fresh yogurt is at its best in the first few weeks of shelf life, after which there is a discernible reduction in sensory characteristics. For example, a Spanish study by Salvador and Fiszman (2004) on whole milk and skim milk flavored, set yogurts showed a gradual deterioration in sensory properties over a 91-day period of storage such that the probability of consumer acceptance was found to be around 40% for the whole milk yogurt and only 15% for the skim milk yogurt after 91 days' storage at 10°C.

8.5 INDICES OF FAILURE FOR YOGURT

8.5.1 Microbial Spoilage

Yeasts and molds are the principal agents of microbial spoilage of yogurt (Craven et al., 2001). In fresh yogurt products, yeasts and molds may be present due to contamination in the processing operations, including from added fruit preparations, from the packaging materials, or, the filling operations. Also, if the package itself lacks integrity—for example, as a result of faulty seals—then spoilage organisms can enter the product. Filling equipment for yogurt can range from relatively open fillers where no special precautions are taken to prevent atmospheric contamination to ultraclean fillers where the product is filled under an atmosphere of high-efficiency particulate air (HEPA)-filtered, laminar-flow air (usually class 10 to 100) and the packaging materials are subjected to a decontamination treatment, such as UVC light, infrared light, or even H_2O_2 vapor or steam sterilization. In order to achieve excellent quality throughout shelf lives of up to 6 or 7 weeks, which are required in some markets, most large, modern yogurt production operations use ultraclean fillers, whether of the form–fill–seal or preformed cup type, and great care is taken to prevent contamination from yeasts and molds. For example, monitoring of the factory air and of fruit preparations for yeasts and molds may be conducted.

As mentioned, fruit preparations can be a source of yeasts and molds. The technology for production and supply of fruit preparations and for dosing them into yogurt either in-line or at the filler ranges from relatively simple to highly sophisticated systems. Fruit preparations may be made so as to be "commercially sterile," meaning free from viable yeasts and molds, and supplied in bulk stainless steel containers or plastic bags (which may be metalized to provide a light barrier to protect against fading of light-sensitive fruit colors) contained in specially designed pallet-sized containers or in smaller, flexible, bag-in-box systems. When these "aseptic" fruit preparations are used, there must be strict attention to proper processing and contamination-free filling by the fruit preparation supplier and strict attention to the prevention of contamination in coupling the fruit preparation container to the fruit dosing system at the yogurt manufacturing facility. Contamination by yeasts

and molds almost inevitably leads to growth, with the potential for spoilage of the yogurt product to which the fruit is added. For this reason, for bulk rigid containers of fruit preparation, N_2 may be used as the headspace gas and changes in headspace CO_2 concentration may be monitored as an indicator of yeast growth. Where procedures cannot be relied on to ensure contamination-free operation, preservatives such as sorbic acid may be added to the fruit preparation where regulations permit.

With good control during manufacturing, the shelf life of yogurt products should not be limited by yeast and mold contamination from the processing and filling operations. Where contamination does take place, the results can be catastrophic, including expensive product retrievals or recalls from the market. For this reason, there has been some work on high pressure processing (HPP) techniques aimed at the postpackaging destruction of yeasts and molds without affecting the viability of the yogurt starter and probiotic organisms. In particular, Carroll (2006) has outlined work done by Fonterra Co-operative Group Limited. However, the technology is expensive. Also, packages, including closures, must be selected for suitability for HPP, as the packages are submerged in water during processing. For simpler factory operations, such as those using open fillers with no decontamination of packaging materials, the reliable shelf life of products is likely to be less than 6 weeks, and if the factory environment contains significant levels of yeasts and molds, the shelf life may be considerably less than this.

Some deterioration of the product during its shelf life due to bacterial action is inevitable: first, due to the continuing action of the yogurt culture bacteria and, second, due to spore-forming bacteria that survive the heat treatment, as the yogurt mix is not usually sterilized. The normal result is the slow development of a cheesy flavor. For highly flavored products, this cheesy flavor may not be apparent for some weeks after production, but for plain products, it may start to become apparent within a couple of weeks. Modified atmospheres in the package headspace have been used to retard microbial growth and hence improve shelf life (Lewis and Dale, 2000). Nitrogen has been used to retard the growth of any yeasts or molds present, and CO_2 has been used to retard the growth of spoilage bacteria. However, industrially the use of modified atmospheres in package headspaces seems to have found limited use, with manufacturers concentrating instead on cleanliness and sanitation to minimize contamination, including the use of ultraclean filling machines.

For pasteurized yogurt products, microbial spoilage due to yeasts and molds should not be an issue if the processing and packaging operations are well controlled. Depending on the pasteurization conditions, spoilage due to bacterial action is also delayed.

Postacidification will reduce the product pH and also the sensory appeal if the yogurt cultures continue to produce significant amounts of acid after packaging and final cooling. In recent years there has been a trend toward milder, less acidic yogurt products, and culture suppliers have developed yogurt cultures with low postacidification characteristics. Maintaining a good cold chain is also necessary to reduce postacidification.

Yogurt is a delicate product with a pleasant texture. However, if the product is not well made, or if the package does not provide sufficient protection during transport and distribution, syneresis can occur, with a resulting separation of whey or serum. Syneresis may also occur if there is continuing acid production by the yogurt starter cultures, and so it is important to select starter cultures with low postacidification properties. It is also important to minimize the stresses the yogurt coagulum is subjected to during physical distribution. Serum separation is unsightly, and in extreme cases the yogurt coagulum may visibly contract in the container. Polystyrene (PS) is the most common material used for yogurt packaging. However, PS is brittle and, so, usually contains a rubberizing compound such as butadiene to give the package flexibility; the resulting material is known as high-impact polystyrene (HIPS). The flexibility of HIPS both provides some degree of cushion to the product and protects against splitting of the container during transport, which can occur, especially if the design or forming of the package creates thin or weak spots.

8.5.2 Viable Organisms

An important index of failure for fresh yogurt is the level of viable organisms in the product. This is true for both the basic yogurt starter organisms and for added probiotic cultures. According to regulations in various parts of the world, yogurt must contain either a certain level of viable organisms or viable starter culture organisms at an unspecified level. For example, the Codex Alimentarius (2003) provides a guide that there should be a minimum of 10^7 colony-forming units (cfu) g^{-1} of the microorganisms constituting the starter culture and a minimum of 10^6 cfu g^{-1} of any "labeled" microorganisms if a claim is made for their presence. The regulations in France (French Decree, 1988) and Japan (Japanese Ordinance, 1951) also specify 10^7 cfu g^{-1}, whereas those in China (China National Standard GB 2746, 1999) and Australia (ANZFSC, 2008) specify 10^6 cfu g^{-1}. It is generally agreed that probiotic organisms should be present at 10^6 cfu g^{-1} or more in order to be effective in gut health (Shah, 2000; Talwalkar and Kailasapathy, 2004; Vasiljevic and Shah, 2008).

Thus, there is a need to ensure that throughout the shelf life the starter organisms and any added probiotic organisms retain sufficient viability to meet national regulations and label claims made by the manufacturer. The viable counts of most cultures used in making yogurt or added as probiotics to yogurt decline slowly throughout the shelf life whatever package is used. However, some strains of probiotics are known to be O_2-sensitive in broth culture, although the situation in yogurt is less clear (Talwalkar, 2003). Thus, considerable work has been done to investigate the effect of O_2 on various cultures, the effect of packaging materials on survival of cultures in yogurt, and the use of techniques such as encapsulation and O_2 scavengers to protect probiotic organisms from exposure to O_2. This work is discussed in the following text.

8.5.3 Flavor Changes

Most yogurt products are fresh rather than pasteurized and contain live cultures. Unless they are highly flavored, the flavor is delicate and subtle. Accordingly, there is a natural staling of the product throughout the shelf life due to bacterial metabolism, even in an impermeable package. However, this staling process may be increased if the package is permeable to gases, allowing product volatiles such as acetaldehyde to escape. If light is able to affect the product, light-induced oxidation may also occur, and the colors of flavored or fruited yogurt may fade or change during shelf life, reducing the eye appeal of the product. Anthocyanin pigments in red fruits and β-carotene in yellow products are examples of colors whose fading is accelerated in the presence of light. Both O_2 and light can affect fading, so choice of packaging material can influence the rate of deterioration. In practice, selection of the package type and design depends on a number of criteria, including cost, as the margins obtainable from the market are generally modest. So HIPS, although relatively permeable to O_2 (Robertson, 2006a), is the most common packaging material due to its other advantages, such as ease of thermoforming, mechanical properties, and competitive cost.

8.5.4 Oxidation

Vitamins such as riboflavin and ascorbic acid, and functional ingredients such as long-chain omega-3 fatty acids, that are susceptible to oxidation may be components of functional yogurt products. Protection from O_2, light, or both may be needed in order to ensure that the potency of these active ingredients is maintained and also that off-flavors due to degradation products are avoided. Tamime and Robinson (1999d) discussed changes in vitamins during the production process and subsequent storage and summarized the situations as follows: dissolved O_2 can reduce significantly the content of vitamins C, B_6, B_{12} and folic acid; depending on the particular strains of yogurt starter cultures, vitamins such as thiamin and biotin may be utilized and hence decreased, although some starter cultures produce folic acid, niacin, biotin, and riboflavin during metabolism, causing an increase. Deschênes (2006), in a recent review, stated that data for the effect of packaging on the

shelf life of functional foods and their bioactive components are scarce, fragmented, and dispersed within the literature and suggested that a review of the current literature would be useful. She could, though, report that conjugated linoleic acid levels in yogurt did not vary over the normal shelf life. Sanguansri and Augustin (2006) reported that omega-3 fatty acids, because of their high degree of unsaturation, are very susceptible to oxidation and the development of objectionable off-flavors and odors. Sharma et al. (2003) showed that in a drinking yogurt, omega-3 fatty acids from tuna oil in an encapsulated form gave higher acceptability scores than those in the free form.

8.6 PACKAGING MATERIALS FOR YOGURT

A wide range of packaging materials is used for yogurt products (Brody, 2006; Nilsen et al., 2002; Tamime and Robinson, 1999e).

The most popular material by far in current use for spoonable yogurt (either set or stirred) is thermoformed HIPS in the form of small cups or larger tubs, with either an aluminum foil/plastic laminate or a paper/plastic laminate heat-seal lid or closure. These containers may be produced in form–fill–seal packaging machines or be delivered preformed from packaging materials suppliers. It is normal to add pigments such as TiO_2 to the HIPS in order to improve the appearance of the package and to provide some barrier to light. This also helps in heating and softening the HIPS sheet for thermoforming when radiant heating is used (Robertson, 2006b). White is most often used, but other colors are also common. Also, often for form–fill–seal containers and sometimes for preformed cups, labels are applied that provide a further barrier to light. A HIPS sheet for forming into small containers in form–fill–seal fillers is usually around 1.0–1.4 mm thick and the containers produced have wall thicknesses of around 0.2 mm. Preformed HIPS containers may have wall thicknesses around 0.25–0.5 mm. Injection-molded polypropylene (PP) containers can be around 0.5–1 mm in wall thickness [Pritchard W.J. (www.itechnik.com.au) 2008, personal communication].

Rectangular paperboard cartons or cups (with or without an aluminum foil layer), glass containers, PP, and blow-molded high density polyethylene (HDPE) containers are all in common use; poly(ethylene terephthalate) (PET), polyvinyl chloride (PVC), polyvinylidene chloride copolymer (PVdC), and polylactate (PLA) have also been used or proposed, and for some specialty products in some markets, ceramic containers have been used (Frederiksen et al., 2003; Tamime and Robinson, 1999e).

For pasteurized, spoonable yogurt products, laminated materials are desirable if a long shelf life is needed, with some having shelf lives of 4–6 months at ambient temperatures. For these products, a low water vapor transmission rate (WVTR) is required to stop the product losing water during shelf life. A good O_2 barrier will help to protect the product from oxidation, and a good light barrier will help to delay fading of light-sensitive colors and to avoid light-induced oxidation.

Drinking-yogurt products are becoming increasingly popular. For these products, the most popular containers are HDPE bottles sealed with either aluminum foil laminate heat-seal closures or with low density polyethylene (LDPE) snap or screw caps. Bottles made from other plastics (e.g., PET) may also be used. For bottles it is common for shrink-sleeves to be used for labeling and decoration. For long-life, heat-treated drinking-yogurt products, plastic/alufoil/paperboard laminate cartons with good water vapor, O_2, and light barrier properties are also often used.

8.7 SHELF LIFE OF YOGURT IN DIFFERENT PACKAGES

As with virtually all packaged food products, the package in which a yogurt product is provided to the consumer is of major importance. It must provide a safe, convenient, attractive, functional, and cost-effective means for protecting the product throughout distribution and merchandising, for presenting it to the consumer, and for enabling easy consumption. Factors affecting the environmental impact of packaging must also be taken into consideration, and these are likely to become even more important in the future. Thus, selection of the packaging materials and of the package design

must take into consideration physical product protection, protection of sensory properties, food safety, and aesthetic, functional, environmental, and cost issues. The market for yogurt products is a competitive one in which innovation plays a significant role. In common with many segments of the food industry, there are several subsegments, ranging from those that offer value propositions to consumers and in which cost considerations are paramount (remembering that the package cost is likely to be a large part of the ex-factory cost) to those in which novel offerings may require either special properties for product protection or design characteristics to ensure the product stands out from the competition on retail shelves.

In recent years, the addition of probiotic cultures to yogurt has become increasingly popular. There has been much research on the health-giving properties of various probiotic cultures, and it is now clear that certain probiotic cultures, consumed regularly and in sufficient quantities, can assist health and well-being (Mattila-Sandholm et al., 2002; Vasiljevic and Shah, 2008). Probiotic cultures vary in their sensitivity to O_2 (Dave and Shah, 1997; Talwalkar, 2003; Talwalkar and Kailasapathy, 2004), at least in broth cultures, and it has been shown that numbers of some species of *Bifidobacterium* and *Lactobacillus* reduce significantly during the shelf life of probiotic yogurts. Although this can be due to a number of factors, including the acidic pH, it has stimulated research aimed at elucidating the effect of O_2 on survival of probiotics during shelf life and on approaches to reducing the O_2 content of yogurt, including approaches involving packaging.

Several approaches have been considered: the use of packaging materials that are less permeable to O_2 (Miller, 2003), the use of O_2-scavenging packaging materials (Miller, 2003), the addition of an O_2 scavenger to the yogurt (Dave and Shah, 1997), the encapsulation of O_2-sensitive probiotic cultures to protect them from O_2 in the yogurt (Kailasapathy, 2006), variations in production methods to reduce product O_2 levels (Miller, 2003), the addition of prebiotic compounds (Donkor et al., 2007a; Juhkam et al., 2007), and the addition of whey protein concentrate (Antunes et al., 2005). However, it should be noted that the most widely used approach in commercial practice is to select probiotic strains with robust technological properties, meaning the ability to maintain good viability throughout shelf life under normal commercial manufacturing and storage conditions (Mattila-Sandholm et al., 2002). For example, Miller (2003) showed that the survival of both *Lactobacillus acidophilus* strain 2409 and *Bifodobacterium infantis* strain 1912 was not significantly reduced in either normal set yogurt or in O_2-reduced yogurt, with levels being maintained well in excess of 10^7 cfu g^{-1} over 42 days of refrigerated storage.

The application of a shrink-sleeve label may provide a significantly increased barrier to O_2 transmission (and to light transmission too, if it is opaque). Shrink-sleeves of PS and PVC are in common use to label and decorate small bottles of probiotic drinking yogurt. These bottles are often closed with an aluminum foil lid, and it is possible that the combination of shrink-sleeve and foil lid provides a measure of protection against O_2 permeation. Miller (2003) showed that the O_2 level in yogurt depended on a number of factors, including aspects of the production method as well as permeation through the packaging material. For HIPS containers, the thickness of the material at various points of the package appeared to influence the O_2 content in the near vicinity, and the O_2 level increased throughout the package during storage to levels of around 12.5 ppm by day 35 of a total of 42 days of storage. This O_2 level was similar to the saturation point of O_2 in water at the storage temperature of 4°C. These results were not surprising given the relative permeability of HIPS to O_2. This study also showed that using a HIPS/tie/EVOH/tie-layer/LDPE (where EVOH is ethylene vinyl alcohol copolymer) laminate material (NuPak) resulted in reduced O_2 content in the yogurt compared with straight HIPS over 42 days of storage, as shown in Figure 8.2.

Miller (2003) also showed that adding an O_2 scavenger ($ZerO_2$) to the packaging material further reduced the O_2 content, particularly for set yogurt over the first few weeks of a 6-week storage trial.

Adding ascorbic acid to yogurt has been shown to protect a *La. acidophilus* strain (strain not specified) to some extent, but the counts of bifidobacteria remained unaffected (Dave and Shah, 1997). A similar effect was reported with l-cysteine and some bifidobacteria (Collins and Hall,

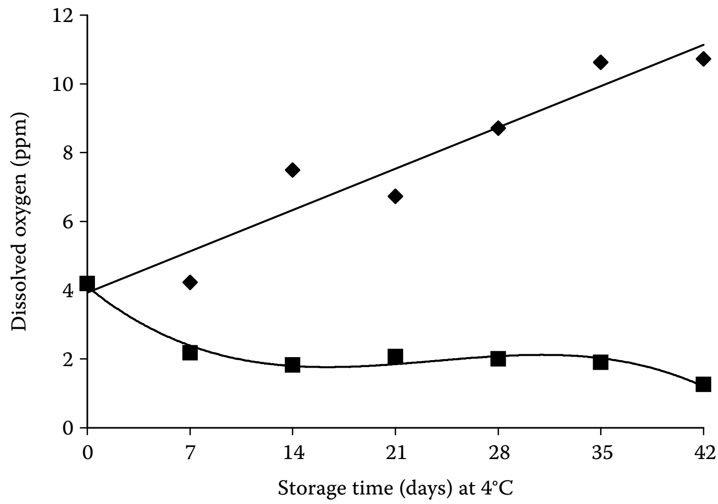

FIGURE 8.2 Oxygen levels in yogurt stored for 42 days at 4°C in HIPS (♦) and NuPack (■) packaging material. (From Miller C.W. 2003. *A Study of Packaging Methods to Reduce the Dissolved Oxygen Content in Probiotic Yoghurt.* Sydney, Australia: Centre for Advanced Food Research, University of Western Sydney, Ph.D. Thesis, with permission.)

1984). Encapsulation in an alginate polymer assisted the survival of *La. acidophilus* strain DD910 and *Bifidobacterium lactis* strain DD920 (Kailasapathy, 2006). However, Donkor et al. (2007b) found, in a study on a commercial yogurt containing the probiotics *Lactobacillus rhamnosis* GG and *Bifidobacterium animalis* Bb-12, that there were stable counts of these cultures throughout 4 weeks of storage at levels exceeding the accepted required minimum of 10^6 live cells mL^{-1} of product. Furthermore, there was very little change in viable populations of the yogurt starter cultures *Streptococcus thermophilus* and *La. delbrueckii* subsp. *bulgaricus*. This commercial yogurt (brand name Vaalia) was packaged in HIPS containers. This Vaalia yogurt did, however, contain the prebiotic inulin, which may have provided a protective effect. There have been studies showing positive effects on the survival of probiotics due to the presence of prebiotics such as inulin, oligofructose, and Hi-Maize high-amylose corn starch (Donkor et al., 2007a; Juhkam et al., 2007), and also for whey protein concentrate (Antunes et al., 2005).

A Polish study of *La. acidophilus*, *Bifidobacterium bifidum*, and *Streptococcus thermophilus* counts in goat and cow milk bioyogurt packaged in glass, HDPE, PS, and PP over 21 days found that for *La. acidophilus* the package type had no effect; for *B. bifidum* HDPE gave the best results, and for *St. thermophilus* HDPE was best for cow milk bioyogurt and PS was best for goat milk bioyogurt (Kudelka, 2006).

A recent review on the subject of packaging systems and probiotic dairy foods discusses some of the principles and also differing results found in various studies (da Cruz et al., 2007). It appears that there are significant strain differences in the sensitivity to O_2 of various probiotic cultures; also, differences in formulations and processing systems can influence the survival of probiotic cultures. Adding to the difficulties of interpreting some of the data is the fact remarked upon by some authors that enumeration methods for probiotic cultures can give misleading results unless properly verified. All these factors must be borne in mind when selecting probiotic cultures for yogurt, designing the formulations, and selecting suitable materials for packaging the product. The results discussed above for the effect of O_2 levels on probiotic cultures may also be useful when choosing packaging materials for yogurts containing O_2-sensitive functional ingredients such as long-chain omega-3 fatty acids. From a practical point of view, there can be no substitute for careful trials with the actual product in the proposed packaging material and format, ensuring that analysis methods are proven and able to give clear results.

A recent comprehensive study and discussion of the effect of some packaging materials on the flavor of strawberry-flavored, stirred yogurts of 0% and 4% fat content during their shelf life showed interesting differences between glass packaging as a reference, PP, and 50/50 PS/HIPS (Saint-Eve et al., 2008). In common with a previous study by Salvador and Fiszman (2004), mentioned earlier, 0% fat yogurt was found to deteriorate faster than 4% fat yogurt regardless of the packaging type. It was also concluded that PS/HIPS seemed to be preferable to PP for avoiding the loss of fruity notes and for hindering the development of odor and aroma defects, particularly for 4% fat yogurts. Earlier studies on the influence of light transmittance and gas permeability on the quality of whole natural yogurt during storage have been reviewed and summarized by Tamime and Robinson (1999e). Their summary showed that the greatest protection from light and O_2 combined was provided by colored glass, with decreasing degrees of protection as the packaging material was either more permeable to O_2 or more transparent to light. They also concluded that packaging materials of low O_2 permeability should be used for long-life or pasteurized yogurt. However, although packaging materials can have some effect on the shelf life of yogurt, the hygiene of the production and filling operations and the storage temperature have major impacts. Tamime and Robinson (1999e) stated that in the absence of aseptic production and filling, and at a storage temperature of 8°C, shelf life should not exceed 16–18 days. Such a shelf life would not be commercially viable in most developed markets today.

Light can induce oxidation of dairy products, including yogurt. Riboflavin, naturally present in yogurt, can absorb visual light and react as a photosensitizer. Oxygen is also necessary, and the end results of this light-induced oxidation are protein and lipid degradation with resultant off-flavors. Opaque or semi-opaque packaging materials, most usually containing a white pigment such as TiO_2, are normally used for yogurt. However, for clear glass or plastic packages and for thin-walled HIPS packages, significant light may penetrate into the product. This can be a consideration for plain yogurt products with delicate flavors. Secondary packaging such as overwraps will help to reduce light penetration. PLA as a biobased packaging material has been used for some yogurt products with an environmental or organic market positioning, and a study of the effect of light-induced changes in plain yogurt gave similar or better results than PS (Frederiksen et al., 2003).

There are yogurt products available that comprise two parts: one part containing yogurt and the other containing an auxiliary product, for example, a cereal product such as muesli that can be mixed with the yogurt, or fruit or a flavored syrup or similar foods. Some packages present the two components side by side within the same package; others present the two components as separate packages joined together in "piggyback" formats, for example. Selection of the packaging material must have regard to the particular properties of these components. For example, WVTRs are not of critical importance in a yogurt product with a shelf life of a few weeks but are of critical importance for a cereal product, which must retain its "crunch" in order to appeal to consumers. For an auxiliary product susceptible to oxidation, oxygen transmission rates (OTRs) may be critical, and protection from light may be important for a fruit product containing light-sensitive color compounds such as anthocyanin pigments, which give the red–purple–blue color of some fruits. It is important to assess the needs of the total product for protection before deciding on the packaging materials (both the container material and the closure material) for a side-by-side package or for a two-part package. With good-quality raw materials and appropriate selection of packaging materials, it should be possible to ensure that the shelf life of the auxiliary product is no less than that of the yogurt. It is worth stating again that the standard and hygiene of processing and filling operations is what normally determines the shelf life of yogurt products. The shelf life of "fresh" yogurt may be only a couple of weeks for unprotected operations and up to 6 weeks or more for well-operated, ultraclean operations.

8.8 CONCLUSIONS

Many packaging materials mentioned in this chapter are successfully used as primary packages for spoonable or drinking-yogurt products. The choice of a material and a package form will depend on

several factors, including physical product protection; the required shelf life and the indices of failure for the particular product; legislation and guidelines regarding packaging materials; marketing considerations regarding appearance, product presentation, and product usage; special requirements of the retail trade, such as desired package dimensions for optimal shelf space utilization or shelf-ready packaging; economic considerations relating to capital costs for filling equipment and packaging line equipment, operating costs for packaging materials, including waste and filling machine operating costs, and commercial margins available in the relevant market; and, increasingly, environmental considerations.

Packaging technologists must work with other members of development teams to find the optimal solutions for each project, whether for developing new products or for value management reviews of existing products. Collaboration across the supply chain between suppliers of packaging equipment, packaging materials suppliers, food manufacturing and marketing companies, and retailers is becoming increasingly common and may even be regarded as a necessity in order to achieve the best results in package design and implementation. First principles should be applied whenever possible, but there is no substitute for adequate premarket trials to ensure the proposed packaging system is performing as intended.

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